The Implications of Zero Growth

Analysed with an Agent-Based Model

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Abstract

This paper presents a macroeconomic agent-based model used to analyse the imperative question of whether a stable zero-growth economy with interest bearing debt is a viable option for humanities future. As the ever approaching limits of the Earth's biosphere challenge the status quo of boundless exponential growth, it is essential to ascertain the potential detriments such a zero-growth state would have on the macroeconomy. This research presents a comparison between a growth and a zero-growth scenario on the model, used to assess the relative consequences of such a policy. It was found that a stable zero-growth path is possible for the model, furthermore, the relative implications of zero-growth do not have calamitous effects on the model. It was found that firms were more likely to go bankrupt, unemployment remained at slightly higher levels, and average inflation was also marginally higher in the zero-growth scenario. However, wealth inequality was lower and growth rates of real GDP were more stable.

Contents

1 Introduction

As John Stuart Mill remarked “the increase of wealth is not boundless; that at the end of what they term the progressive state lies the stationary state” (Mill, 1884, p. 514), illuminating the imperative to discern the implications that a zero-growth steady state era will have on economic welfare. Albeit seemingly distant in sight it is the ineluctable destination of our current trajectory, as across the developed world growth rates have slowed to a “new normal” of 1% (Malmaeus and Alfredsson, 2017). Although, the prosperity ruminated by Keynes (1930) has not culminated to his reverie as of yet, mired by inequality (Piketty, 2014, p. 327) and humanities’ insatiable appetite, with only a decade for his vision to be realised, the lustrous steady state of affluence and abundance is still sequestered from our reach. Perhaps we have not yet paid our due to the gods of avarice and usury (Keynes, 2010), with a little more growth will we ever reach this aspiration? “And then the question beyond, where history offers us only fragments: what to do when the increase in real income itself loses its charm?”(Rostow, 1960, p. 16); for indeed this charm is wearing thin. Decades of warnings of the potential consequences of our persistent pursuit of productivity growth and technological progress (Meadows et al., 1972) seem to be frivolous in mitigating humanities strain on the planet. Schumacher proposes that economic growth will “necessarily run into decisive bottlenecks when viewed from the point of view of the environmental sciences” (Schumacher, 1973, p. 16), which has become progressively lucid in recent years. Steffen et al. (2015) classify nine planetary boundaries for which human overshoot could lead to potential destabilizing effects on the ecosystem, four are already considered being in the zone of uncertainty, for which two are classified as high risk, beyond the zone of uncertainty. Therefore, it is crucial to analyse the impacts that a post-growth era would have on the economy.

Current mainstream economic modelling, particularly those of dynamic stochastic general equilibrium (DSGE) models have come under recent criticism, even from their authors of conception: “a mainstream economist like me insists that every proposition must pass the smell test: does this really make sense? I do not think that the currently popular DSGE models pass the smell test” (Solow, 2010, p. 2). Furthermore, Mankiw asserts that “from the standpoint of macroeconomic engineering, the work of the past several decades looks like an unfortunate wrong turn” (Mankiw, 2006, p. 21). Blanchard encapsulates the gap in current macroeconomic modelling, in which “it would be nice if there was a model that did both, namely had a tight, elegant, theoretical structure and fitted the data well. But this is a dangerous illusion” (Blanchard, 2018, p. 51). However, can this space be filled by recent techniques developed in complex systems modelling? Namely that of agent-based models (ABMs); arguably, they at least fulfil Blanchard's first request. ABMs are a type of computational model in which there are numerous 'agents' interacting with each other, such as firms, households, or even particles or cells. This computational framework allows the modeler to create a system from the micro-foundations upwards, leading to emergent properties[1], which allow the modeler to analyse the macro dynamics of the system. When developing a model, the modeller must be wary of the Lucas critique, which states that it is erroneous to try predict economic dynamics resulting from a change of policy purely based on historical data (Lucas Jr, 1976). Agent-based models avoid this critique because they do not depend on observed data, instead the modeller seeks to determine the deep parameters and processes of individual agents' behaviour. Thus, due to the lack of historical data for economies sustaining a steady state and the recent critiques of DSGE models, an ABM will best suffice to analyse the implications of zero-growth.

The structure of the paper is as follows. Section 2 discusses the relevant literature on post-growth economics and macroeconomic ABMs. Section 3 provides an overview of the model details and assumptions regarding the agent's behaviour. Section 4 presents the results and discussion from simulations. Section 5 acknowledges the limitations of this research and further extensions to be made. Finally, section 6 contains a summary and concluding remarks.

2 Literature Review

The literature concerning ecological macroeconomics, post-growth macroeconomics, and agent-based macroeconomic modelling has burgeoned in recent years, however, there remains a deficit of a synthesis between these topics. Barrett (2018) performed a highly novel analysis of the stability of zero-growth on the macroeconomy. The paper explored macroeconomic dynamics of a model built from coupled non-linear differential equations, which capture the relation between the rates of change of different variables, resulting in a robust and dynamic model. This allowed for the presence and analysis of economic fluctuations and crises that cannot be gleaned from conventional DSGE models, giving insight into the importance of debt and credit on economic performance, among other findings. The comparison in the paper was done by tweaking a productivity growth input parameter, which was set at either 2% or zero. Then, when the model was simulated, GDP growth would fluctuate around these respective values. The model, based on work by Keen (1995), incorporated elements of Minsky's Financial Instability Hypothesis (FIH). The FIH highlights the

[1]Emergent properties is the phenomenon in which an entity has attributes that its individual parts do not have on their own.

instability of the capitalist market mechanism and the role of financial attributes that are essential to capitalism in creating economic crises, especially regarding high levels of interest bearing debt (Minsky, 1986, p. 173). A Minskyan model had not before been analysed in the context of zero-growth economics. The results of this paper showed that, for a class of models, zero-growth scenarios are generally no less stable than growth scenarios. However, because of the top-down nature of this model, the microfoundations of the likes of individual household and business behaviour were amiss. Hence, this type of model is unable to capture the emergent properties of the market.

Other models focused on analysing the impacts of zero-growth on an economy with interest bearing debt, and whether this creates in inherent 'growth imperative', include that of Jackson and Victor (2015). In this paper the authors present an analysis of the effects of a transition from a growth scenario to a stationary state economy, among other experiments. The model developed in this paper followed that of the systems dynamics stock-flow consistent variety, aptly called the Financial Assets and Liabilities in a Stock-Flow consistent Framework (FALSTAFF). The authors then used FALSTAFF to simulate an assortment of scenarios, of interest to this paper is scenario 7 in which grow is initialised at 2% and then reduces to zero over the course of a decade, remaining at this rate for the rest of the simulation. In this scenario, no significant distributional effects in the net lending positions of the different economic agents in the model were prevalent throughout the entire run of the simulation. However, there are some initial perturbations during the transition period, particularly a negative impact on firms. This paper highlights the possibility of a movement towards a steady state economy with interest-bearing. However, as in Barrett (2018), due to the incorporation of representative agents, the emergent properties of complex networks was not present.

Moving now to the literature focused on the development of macroeconomic ABMs, a key study in the enhancement of these models was that of Gaffeo et al. (2008). This paper presented a model based off of the complex adaptive trivial systems (CATS) framework, consisting of households, consumption firms, and banks. The CATS models were originally developed by Delli Gatti et al. (2003), with further development in Delli Gatti et al. (2005), and Delli Gatti et al. (2010), which focused on firm demography, entry and exit dynamics, and the role of credit in creating macroeconomic fluctuations. The model in Gaffeo et al. (2008) adapted this framework to better represent a full economy with an inbuilt growth imperative into the labour productivity function, described by an AR(1) process with an exponentially distributed random variable that depended on the profit share of output and the research and development (R&D) behaviour of firms. Due to the implementation of banks and a credit market this model was able to produce endogenous crises as an emergent property, which is not evident in Russo et al. (2007), which is approximately the same model without a banking sector. Hence, this implies that a banking sector is essential to a macroeconomic ABM in capturing the dynamics of the business cycle. A further extension to the CATS models is found in Assenza et al. (2015) which expanded the framework to include a capital goods sector as well as a consumption goods sector, households, and a banking sector. The productivity of labour and capital is assumed to be constant and uniform across all firms, hence, the results of this model are unintentionally equivalent to a post-growth analysis. However, Assenza et al. do not take this into account in their analysis of the model, hence, no significant insight is gained as to whether different outcomes would have been prevalent given endogenous specifications for capital and labour productivity. Although, Assenza et al. do demonstrate the importance of an upstream capital sector in fully capturing the real-world dynamics of the business cycle, for which, a full model was needed for a crisis to emerge.

Another successful macroeconomic ABM framework is that of the Keynes meets Schumpeter (K&S) models as seen in Dosi et al. (2006), Dosi et al. (2009), Dosi et al. (2010), and Dosi et al. (2013). These models cultivate a capital sector more complex than those found in the CATS models, where technical development can either occur from innovation or imitation due to the R&D of capital firms. This is the driving force of economic growth in the K&S models, following a Schumpetarian approach to firm behaviour as they are able to capture the essential fact of "creative destruction" (Schumpeter, 1942, p. 83) for a capitalist economy, further highlighting the importance of an upstream capital sector in creating cyclical dynamics.

In recent work by Botte et al. (2021), a synthesis between ecological macroeconomics and macroeconomic ABMs has finally been established. This paper presents a unique analysis of the implications of a transition to a net zero carbon economy on a macroeconomic ABM. The model (TRansit) is extensive in its construction, consisting of a consumption good sector, energy sector, capital good sector, government sector, households/consumer sector, and a banking sector. As in the K&S models, the main driver of growth in TRansit comes from the capital goods sector, which engage in R&D to improve capital firm's own productivity, energy efficiency and labour productivity of a given vintage of machine. Hence, growth is endogenous to the model, therefore, an analysis of zero growth was not conducted in this research. However, the findings regarding the impacts of a transition to a zero-carbon economy are still of interest, in which they found a fast transition would have a negative impact on GDP growth as the economy goes into recession after the transition, followed by a recovery to pre-transition levels as the economy adjusts to the new sources of energy. Thus, this paper filled a necessary gap in the application of ecological macroeconomics to agent-based modelling but has still left scope for research into the consequences of a post-growth regime on a macroeconomic ABM.

3 The Model

3.1 The Agents

The model is populated with four different types of heterogeneous agents: i) there are $i = 1, ..., M_C$ firms producing a homogeneous consumption good (C-firms); ii) a smaller number of $j = 1, ..., M_K$ firms producing a homogeneous capital good (K-firms); iii) $h = 1, ..., M_H$ households that work and consume, and; iv) a single bank which extends loans and keeps agents liquidity as deposits. Each agent makes decisions in discrete time $t = 1, ..., T$, where each time period is assumed to correspond to a quarter of a year.

3.2 Sequence of Events

This sequence of events that occur during each simulation are given below:

1. At the beginning of each time step t, C-firms and K-firms engage in production of their respective goods and calculate their market share. Firms with zero market share exit the market, employees of firms that have left the market become unemployed.

2. New C-firms and K-firms then enter the market, based on the number of bankruptcies from last period, due to negative liquidity, and the number of bankruptcies from zero market share in the current period.

3. Successful incumbents then pay their employees the wage promised in their labour contract, which households then use to consume consumption goods (C-goods) from C-firms on a decentralised market.

4. C-firms then calculate their planned production for the next period, determining their desired investment and employment decisions. C-firms then enter a decentralised market where they can purchase capital goods (K-goods) from K-firms for next periods production.

5. K-firms then calculate their planned production for the next period, and determine their employment decisions.

6. A decentralised labour market then opens where households send applications to firms and are hired on the basis of the firms vacancies and the households reservation wage.

7. C-firms and K-firms then update their prices for the next period and calculate their profits.

8. The bank updates their net worth and calculates the maximum loan they are willing to extend to firms. A market for credit then opens in which firms request their desired loan from the bank, firms are either given the loan in full or the maximum amount the bank is willing to lend.

9. Firms then update their liquidity and exit the market if their liquidity is zero or negative.

3.3 Households

The hth household's desired expenditure is assumed, for simplicity, to be given by a simple Keynesian budget constraint:

$$E^d_{h,t} = c_1 Y_{h,t} + c_2 \Lambda_{h,t}, \tag{1}$$

where $c_1 \in (0, 1)$ is the marginal propensity to consume out of income and $0 < c_2 < c_1$ is the marginal propensity to consume out of wealth[2] (see Appendix A for parameters and initial values).

The income that household h receives from their employer is given by the wage specified in their labour contract:

$$Y_{h,t} = \mathbf{1}_{h,t} w_{\iota,t}, \tag{2}$$

where $w_{\iota,t}$ denotes the wage rate of firm[3] ι and $\mathbf{1}_{h,t}$ is a dummy variable; $\mathbf{1}_{h,t} = 1$ if household h is employed and $\mathbf{1}_{h,t} = 0$ if household h is unemployed. Households update their reservation wage in accordance with inflation and their employment status:

$$w_{h,t+1} = \begin{cases} w_{h,t}(1 + f_t)(1 + \zeta_{h,t}) & \text{if } \mathbf{1}_{h,t} = 1 \\ w_{h,t}(1 + f_t)(1 - \zeta_{h,t}) & \text{if } \mathbf{1}_{h,t} = 0, \end{cases} \tag{3}$$

where $\zeta_{h,t}$ is a uniform random variable positively distributed on the support $(0, U_\zeta)$ and $f_t = \Delta P^C_t / P^C_{t-1}$ is a proxy for inflation, where P^C_t is the average price level of C-goods.

Households update their liquidity according to the rule:

$$\Lambda_{h,t} = \Lambda_{h,t-1} + Y_{h,t} - E_{h,t} \tag{4}$$

[2]Household wealth is equivalent to the amount of liquidity that they have stored at the bank, $\Lambda_{h,t}$.
[3]When making reference to either C-firms or K-firms, the symbol ι is used.

where $E_{h,t}$ is household h's actual expenditure on C-goods. Households keep their liquidity as deposits at the bank.

3.4 Consumption Firms

The output of the ith C-firm, $Y_{i,t}$, is assumed to be given by a Leontief production function with constant returns to scale for both labour, $N_{i,t}$, and capital, $K_{i,t}$:

$$Y_{i,t} = \min\left\{a_{i,t}N_{i,t}, \frac{K_{i,t}}{\nu}\right\}, \tag{5}$$

where $a_{i,t}$ is firm i's labour productivity and ν^{-1} is a constant rate of return on capital. Firm i is assumed to desire full capacity utilisation. Thus, when firm i is operating at this rate, output can be expressed as:

$$Y_{i,t} = a_{i,t}N_{i,t} = \frac{K_{i,t}}{\nu}. \tag{6}$$

Labour productivity, $a_{i,t}$, which is the essential variable of growth in the model, determining the efficiency of firm i's production process, is assumed to be given by the following functional form:

$$a_{i,t} = a_{i,t-1}(1 + g + \alpha_{i,t}), \tag{7}$$

where g is the average growth rate of labour productivity, and $\alpha_{\iota,t}$ is the productivity growth of firm i, which represents fluctuations around the average growth rate. The rate of productivity growth of firm i is given by an AR(1) process[4]:

$$\alpha_{\iota,t} = \beta\alpha_{\iota,t-1} + \varepsilon_{\iota,t}. \tag{8}$$

Firm i's goods are assumed to be perishable, thus, their inventories[5] are given by:

$$V_{i,t} = Y_{i,t} - Q_{i,t}, \tag{9}$$

where $Q_{i,t}$ is firm i's total quantity of sold C-goods.

Planned production is similar to the functional form of expected demand in Botte et al.

[4]Here, $\beta \in (0,1)$ determines the "memory" from the previous time step and is chosen such that the autocorrelation function decays at an appropriate rate, $corr\,(\alpha_{i,t}, \alpha_{i,t+n}) = \beta^n$. It is assumed that the error term, $\varepsilon_{i,t}$, follows a normal distribution with mean $\mu = 0$ and a finite and small variance, σ_ε^2. With the assumption of stability, such that $|\beta| < 1$, the standard deviation of the error term is given by $\sigma_\varepsilon = \sigma_\alpha\sqrt{1-\beta^2}$.

[5]Firm i uses inventories, $V_{i,t}$, as a signal of excess supply ($V_{i,t} > 0$) or excess demand ($V_{i,t} = 0$), where firm i's level of desired inventories is zero.

(2021), given by:

$$\hat{Y}_{i,t+1} = \rho\hat{Y}_{i,t} + (1-\rho)Q^d_{i,t}, \tag{10}$$

where $\rho \in (0,1)$ determines the weight firm i puts on current planned production or quantity demanded ($Q^d_{i,t}$) as a predictor for future sales. Hence, through repeated substitution, planned production is the weighted average of past demand.

Firm i sets the price above their expected unit cost of production, and increases their price if there is excess demand for their goods or reduces the price if there is excess supply for their goods:

$$P_{\iota,t+1} = \begin{cases} \max\left\{\upsilon^e_{i,t+1}, P_{i,t}(1+\psi_{i,t})\right\} & \text{if } V_{i,t} = 0 \\ \max\left\{\upsilon^e_{i,t+1}, P_{i,t}(1-\psi_{i,t})\right\} & \text{if } V_{i,t} > 0, \end{cases} \tag{11}$$

where $\psi_{i,t}$ is a uniform random variable positively distributed on the support $(0, U_\psi)$ and $\upsilon^e_{i,t+1} = w_{i,t+1}/a^e_{i,t+1}$ is the expected unit cost of production in the next period, where $a^e_{i,t+1}$ is firm i's expected labour productivity in the next period:

$$a^e_{i,t+1} = a_{i,t}(1 + g + \beta\alpha_{i,t}). \tag{12}$$

The investment of firm i is split into two categories, replacement investment, $I^R_{i,t+1}$, and expansion investment, $I^E_{i,t+1}$. The amount of replacement investment that firm i desires in the next period is given by:

$$I^R_{i,t+1} = \delta K_{i,t}, \tag{13}$$

and the amount of expansion investment firm i desires is:

$$I^E_{i,t+1} = K^d_{i,t+1} - K_{i,t}, \tag{14}$$

where $K^d_{i,t+1}$ is firm i's desired stock of capital, derived from Eq. (6) and Eq. (10) as:

$$K^d_{i,t+1} = \nu\hat{Y}_{i,t+1}. \tag{15}$$

Furthermore, firm i's total desired investment is the sum of replacement and expansion investment, $I^d_{i,t+1} = I^R_{i,t+1} + I^E_{i,t+1} = K^d_{i,t+1} - (1-\delta)K_{i,t}$.

After firm i has purchased K-goods for investment from K-firms they then determine their desired loan from the bank. Similar to Asseza et al. (2014), firm i's desired loan is given by their finance gap, the difference between their net worth and operating cost:

$$L^d_{i,t+1} = \max\left\{w_{i,t}N_{i,t} + \tilde{I}_{i,t+1} - \Lambda_{i,t}, 0\right\}, \tag{16}$$

where $w_{i,t}N_{i,t}$ is the wage bill and $\tilde{I}_{i,t+1}$ is the total cost of investment.

Firm i enters the labour market after they have purchased their desired capital for the next period, hence, firm i knows their production capacity. Therefore, the amount of labour that firm i desires to employ in the next period is given by:

$$N^d_{i,t+1} = \frac{K_{i,t+1}}{\nu a^e_{i,t+1}}. \tag{17}$$

Firm i then decides how many employees they wish to hire or fire in the next period:

$$\eta_{i,t+1} = N^d_{i,t+1} - N_{i,t}. \tag{18}$$

The wage that firm i offers their employees in the next period is given by:

$$w_{i,t+1} = \begin{cases} \max\left\{\bar{w}_{t+1}, w_{i,t}(1+\xi_{i,t})\right\} & \text{if } \eta_{i,t+1} > 0 \\ \max\left\{\bar{w}_{t+1}, w_{i,t}\right\} & \text{if } \eta_{i,t+1} \leq 0. \end{cases} \tag{19}$$

where $\xi_{\iota,t}$ is a uniform random variable positively distributed on the support $(0, U_\xi)$. Hence, firm i's wage rate is nominally sticky downwards. Furthermore, firm i's wage rate will never fall below the minimum wage, $\bar{w}_t$, imposed by an unmodelled government and periodically updated with inflation:

$$\bar{w}_{t+1} = \begin{cases} \bar{w}_t(1+f_t) & \text{if } f_t > 0 \\ \bar{w}_t & \text{if } f_t \leq 0. \end{cases} \tag{20}$$

Firm i's profits are given by their revenue minus the wage bill, the cost of replacement investment, and interest payments on their stock of debt:

$$\Pi_{i,t} = P_{i,t}Q_{i,t} - w_{i,t}N_{i,t} - \tilde{I}^R_{i,t} - rD_{i,t}, \tag{21}$$

where $\tilde{I}^R_{i,t}$ is the actual cost of replacement investment and r is the interest rate on debt, $D_{i,t}$.

The balance sheet identity of firm i implies that their assets must be equal to their liabilities:

$$P^K_t K_{i,t} + \Lambda_{i,t} = A_{i,t} + D_{i,t}, \tag{22}$$

here firm i uses the average price of capital goods, P^K_t, as a proxy for the book value of their stock of capital and $A_{i,t}$ is the net worth of firm i, given by the stock of firm i's profits,

$A_{i,t+1} = A_{i,t} + \Pi_{i,t}$. Hence, the liquidity of firm i is updated by the following rule:

$$\Lambda_{i,t+1} = \Lambda_{i,t} + \Pi_{i,t} + L_{i,t+1} - \phi D_{i,t} - \tilde{I}^E_{i,t+1} \tag{23}$$

where $L_{i,t+1}$ is the actual loan firm i takes out from the bank, $\tilde{I}^E_{i,t}$ is firm i's actual cost of expansionary investment, and $\phi \in (0, 1)$ is the amount of debt repaid each period.

3.5 The Market for Consumption Goods

Each households randomly visits Z_C C-firms[6] and sorts them by ascending selling price. Household h then demands $E^d_{h,t}$ worth of C-goods from the first C-firm on their list. If the first C-firm's inventories run out before household h exceeds their desired expenditure, then household h purchases the remaining C-goods from firm i and moves to the next firm on their list. This process repeats until household h spends all of their budget, or exhausts their list of C-firms.

Thus, after the market for C-goods has closed, households determine their actual expenditure, $E_{h,t}$, C-firms determine their actual quantity of sold goods, $Q_{i,t}$, and the total quantity of goods households demanded, $Q^d_{i,t}$.

3.6 Capital Firms

The specification of the jth K-firms is similar to that of the ith C-firm. However, there are some key differences. Notably, K-firm j is assumed to use labour as their only factor of production, under constant returns to scale. Thus, firm j's production function is given by:

$$Y_{j,t} = a_{j,t} N_{j,t}, \tag{24}$$

where the functional form of labour productivity is the same as it is for C-firm i in Eq. (7). Hence, unlike in some ABMs (Dosi et al., 2010; Botte et al., 2021), capital firms do not update the productivity of the vintages of machine's they sell, only their own production process. Firm j updates their planned production according to Eq. (10) although, capital goods are assumed to be durable. Hence, firm j updates their inventories by:

$$V_{j,t} = V_{j,t-1}(1 - \delta) + Y_{j,t} - Q_{j,t}. \tag{25}$$

Furthermore, K-firms set prices according to the same rule as C-firms, described in Eq. (11).

[6]Household h does not incur any travel costs when they visit the initial Z_C C-firms, however, after this number is reached, travel costs become prohibitively high.

K-firms only demand a loan from the bank if they need to cover their finance gap, hence, firm j's desired loan is given by:

$$L^d_{i,t+1} = \max\left\{w_{i,t}N_{i,t} - \Lambda_{i,t}, 0\right\}. \tag{26}$$

Firm j uses their planned production for the next period to determine their desired amount of labour:

$$N^d_{j,t+1} = \frac{\hat{Y}_{j,t+1}}{a^e_{j,t+1}}, \tag{27}$$

where $a^e_{j,t+1}$ is also specified by Eq. (12). Furthermore, the wage that firm j offers employees is also updated according to Eq. (19) and Eq. (20).

The jth K-firm's profits are given by their revenue minus the wage bill and interest payments on their stock of debt:

$$\Pi_{j,t} = P_{j,t}Q_{j,t} - w_{j,t}N_{j,t} - rD_{j,t}. \tag{28}$$

K-firms do not have a stock of durable assets used for production, hence, the balance sheet identity only consists of their liquidity, net worth, and stock of debt:

$$\Lambda_{j,t} = A_{j,t} + D_{j,t}. \tag{29}$$

Therefore, firm j updates their liquidity as follows:

$$\Lambda_{j,t+1} = \Lambda_{j,t} + \Pi_{j,t} + L_{i,t+1} - \phi D_{i,t}. \tag{30}$$

3.7 The Market for Capital Goods

If $I^d_{i,t+1} > 0$, then the ith C-firm will randomly visit Z_K K-firms[7] and sorts them by ascending selling price. C-firm i then demands $I^d_{i,t+1}$ worth of K-goods from the first K-firm on their list. If the first K-firm's inventories run out before C-firm i meets their investment demand, then C-firm i purchases the remaining K-goods from K-firm j and moves to the next K-firm on their list. This process repeats until C-firm i meets their investment demand, or exhausts their list of K-firms.

Hence, after the market for K-goods has closed, the jth K-firm determines their actual quantity of sold goods, $Q_{j,t}$, and the amount of goods demanded by C-firms, $Q^d_{j,t}$. Furthermore, the ith C-firm determines their actual investment $I_{i,t+1}$ and its associated cost,

[7] As in the market for consumption goods, C-firm i does not incur any travel costs when they visit the initial Z_K K-firms, however, after this number is reached, travel costs become prohibitively high.

in terms of replacement investment $\tilde{I}^R_{i,t}$ and expansion investment $\tilde{I}^E_{i,t}$. Therefore, the new capital stock of C-firm i is given by:

$$K_{i,t+1} = K_{i,t}(1-\delta) + I_{i,t+1}. \tag{31}$$

3.8 The Market for Labour

The labour market is characterised by a search and matching mechanism, similar to that found in Gaffeo et al. (2008). When the labour market opens, firm ι determines their employment decision for the next period and either hires or fires employees depending on the variable $\eta_{\iota,t+1}$. If $\eta_{i,t+1} > 0$, then firm ι post vacancies of $\eta_{i,t+1}$. Otherwise, if $\eta_{\iota,t+1} < 0$, firm ι will fire $\eta_{\iota,t+1}$ employees[8]. Firm ι then offers a labour contract[9] to all their remaining employees.

Each households then applies to a random selection of firms, if household h is employed they will apply to $Z_F - 1$ firms[10] and sort them by descending wage. Household h will accept a new job if there is a firm on there list with open vacancies which is offering a wage higher than their current employers wage and their reservation wage. Otherwise, household h will compare their current employers offered wage with their reservation wage and quite if $w_{h,t+1} > w_{\iota,t+1}$. If household h is unemployed, they will randomly apply to Z_F firms and sort them by descending wage. If firm ι has posted vacancies and $w_{h,t+1} \leq w_{\iota,t+1}$ then household h signs a labour contract with firm ι, otherwise they remain unemployed.

3.9 The Bank

The balance sheet identity of the bank is given by:

$$\Gamma_{b,t} + D_{b,t} = \Lambda_{b,t} + A_{b,t}, \tag{32}$$

where $\Gamma_{b,t}$ denotes the reserves of the bank, deposited at an umodelled central bank, $D_{b,t}$ denotes the total loans extended to firms, $\Lambda_{b,t}$ denotes the total deposits[11] of households and firms, and $A_{b,t}$ is the net worth of the bank. Due to the rigorous accounting framework that is used the bank has powers to both create and destroy money when extending loans. When firm ι takes out a loan from the bank, the bank simultaneously credits firm ι's account, while also increasing the banks stock of loans. Thus, this action, increases both the banks assets

[8]Firm ι randomly chooses workers to fire from their set of employees.

[9]The labour contract the firm ι offers to household h is a single period contract in period $t+1$, with a guaranteed wage rate of $w_{\iota,t+1}$.

[10]Employed household are assumed to also send an application to their current employer.

[11]It is assumed that the bank does not offer any interest on deposits.

and liabilities at the same time, hence, new money has been created equivalent to the size of the loan. Moreover, when firm ι repays a proportion of a loan, this destroys money, because the bank's assets and liabilities are both reduced by the amount of repayment.

The central bank is assumed to mandated a reserve ratio of $\gamma \in (0,1)$ and act as a lender of last resort. Therefore, if the net worth of the bank becomes negative, the central bank will bail them out equivalent to the size of their insolvency:

$$A_{b,t+1} = \max\left\{A_{b,t} + \Pi_{b,t} - B_{b,t}, 0\right\}, \tag{33}$$

where $\Pi_{b,t}$ are the bank's profits, the sum of interest payments from solvent firms, and $B_{b,t}$ denotes bad debt, the sum of all outstanding loans insolvent firms have at the bank.

From the above, it can be shown that the banks total stock of loans is updated by:

$$D_{b,t+1} = D_{b,t} + (1-\gamma)\lambda_{b,t} + \Delta A_{b,t+1}. \tag{34}$$

The amount of new loans the bank is willing to extend to firms is given by a proportion, $\theta \in (0,1)$, of total loans the bank is willing to incur a loss from. Hence, the maximum loan that the bank is willing to extend to firm ι is given by:

$$L^s_{b,t+1} = \theta D_{b,t+1}, \tag{35}$$

hence, θ is equivalent to the banks risk attitude.

3.10 The Market for Credit

The bank is assumed to only offer a single loan to firms each period. The size of the loan firm ι demands from the bank is given by $L^d_{\iota,t+1}$. However, the maximum loan the bank is willing to supply to firm ι is $L^s_{b,t+1}$. Thus, if $L^s_{\iota,t+1} < L^d_{\iota,t+1}$, firm ι may become credit constrained. Therefore, the loan that firm ι actually receives is:

$$L_{\iota,t+1} = \min\left\{L^d_{\iota,t+1}, L^s_{b,t+1}\right\} \tag{36}$$

The bank sets an interest rate of $r \in (0,1)$ on the loan[12] and a repayment rate of $\phi \in (0,1)$. Therefore, the total debt of firm ι is updated by the following rule:

$$D_{\iota,t+1} = D_{\iota,1}(1-\phi) + L_{\iota,t+1}. \tag{37}$$

[12]The interest rate is assumed to be set by the central bank, constant and uniform across all firms.

3.11 Entry & Exit Dynamics

All agents apart from firms are fixed throughout the simulation. The bankruptcy condition of firm ι is assumed to be when liquidity is less than or equal to zero, $\Lambda_{\iota,t} \leq 0$. There is a one to one replacement ratio of firms, thus, if firm ι exits the market a new firm will enter. New entrants are a random copy of incumbent firms with no employees or debt.

4 Simulation Results & Discussion

4.1 Simulated vs Actual Time Series

This section provides a comparison between the properties of the simulated time series, with an average growth rate (g) of 2%, and an actual time series of U.S. data[13]. The simulated time series was run for a batch of 20 Monte Carlo simulations so as to avoid atypical behaviour that may be present due to the implementation of random variables[14]. Each simulation was run for 500 periods, discarding the first 100 periods to remove any transient behaviour from the analysis. Hence, the simulated time series is given by the average of these 20 simulations. Both the simulated and actual time series were passed through a Hodrick-Prescott filter (HPF) so as to remove the trend from the data so that the cyclical component of each time series could be analysed. It can be noted from Figure 1 that overall the simulated time series fairs well in capturing similar autocorrelation, which is the correlation in time t with time $t - lag$, in the cyclical behaviour for GDP, consumption, investment, and unemployment.

Figure 2 presents further comparisons of the attributes of the simulated time series with the actual time series, displaying plots of cross correlation, which is the correlation of two series as a function of the displacement of one time series in $t \pm lag$ with the other in time t. From panels 2a and 2b, which displays the cross correlation of GDP with itself, it can be noted that the the simulated time series does relatively well in replicating similar behaviour to that of the actual time series. However, in panels 2c and 2d the relationship is not as strong between the simulated and actual time series for consumption. Furthermore, from panels 2e and 2f the simulated time series does relatively poorly in reproducing the properties of investment as seen in the actual time series. Finally, in panels 2h and 2g, the cross correlation of unemployment has a similar shape but with stronger positive lags in the

[13]The actual time series used for comparison is from the United States, taken from the Federal Reserves (FRED) database at: `https://fred.stlouisfed.org/`. The codes used for the different time series are as follows; GDPC1 for real GDP, PCECC96 for consumption, GPDIC1 for investment, and LRUN64TTUSQ156N for unemployment. All time series had a quarterly frequency from Q1 1947 to Q1 2021, apart from unemployment which was only from Q1 1960 to Q1 2021.

[14]The same random seed was used for each simulation in the two scenarios, so as to avoid differences based on the random numbers that were generated.

simulated time series.

4.2 Growth vs. Zero-Growth

A comparison between two simulated scenarios is now presented to discern the implication on the simulated economy of a steady state era with zero productivity growth. As in Barrett (2018), the growth scenario was simulated with an average growth rate of labour productivity (g) of 2%, and the zero-growth scenario was simulated with an average growth rate of labour productivity 0%. To compare these two scenarios, first, the generic time series of real GDP, real GDP growth and inflation are presented in Figure 3. It is evident that GDP, measured by the total of consumption and investment, is significantly higher in the growth scenario, which was expected. From Table 1, it can be noted that the growth rate of real GDP is more stable in the zero-growth scenario than the growth scenario, with an average standard deviation of 5.2% compared to 6.7%. A Jarque-Bera and Anderson-Darling test was conducted for each scenario to discern whether growth rates followed a normal distribution, it was found that the null hypothesis for each test could not be rejected at the 1% significance level[15], hence, the distributions of real GDP growth rates for both scenarios are not statistically different from a normal distribution. Therefore, an F-test was conducted to test the significance of the difference in variance between the two scenarios. It was found there was a significant difference at the 1% level, with a test statistic of 1.66. The rate of inflation seems to be higher, on average, in the zero-growth scenario when compared to the growth scenario, with a mean of 5.2% compared to 4.6%, respectively. Again, a Jarque-Bera and Anderson-Darling test were conduced which found that the distributions were not statistically different at the 1% significance level[16] from a normal distribution. Therefore, given that the two distributions have equal variances, as seen in Table 1, a two sample t-test was conducted which found a statistical difference in means at the 1% significance level, with a test statistic of 41.45, implying that inflation in the zero-growth scenario is significantly higher than the growth scenario.

Figure 4 presents indices regarding the market stability between the two scenarios. The

[15] The p-Value and test statistic for the Jarque-Bera test was 2.89 and 0.23, respectively, for the growth scenario and 2.35 and 0.31 for the zero-growth scenario. For the Anderson-Darling test the test statistic was 0.78 for the growth scenario and 0.37 for the zero-growth scenario, hence, both were less than the critical value of 1.08 for a 1% significance level. Therefore, the null hypothesis for each test, that the distribution is normally distributed could not be rejected at the 1% significance level.

[16] The p-Value and test statistic for the Jarque-Bera test was 0.85 and 0.65, respectively, for the growth scenario and 1.48 and 0.48 for the zero-growth scenario. For the Anderson-Darling test the test statistic was 0.29 for the growth scenario and 0.25 for the zero-growth scenario, less than the critical value of 1.08 for a 1% significance level. Thus, the null hypothesis for each test, that the distribution is normally distributed could not be rejected at the 1% significance level.

Figure 1: Autocorrelation of Simulated and Actual Time series for Key Macroeconomic Variables

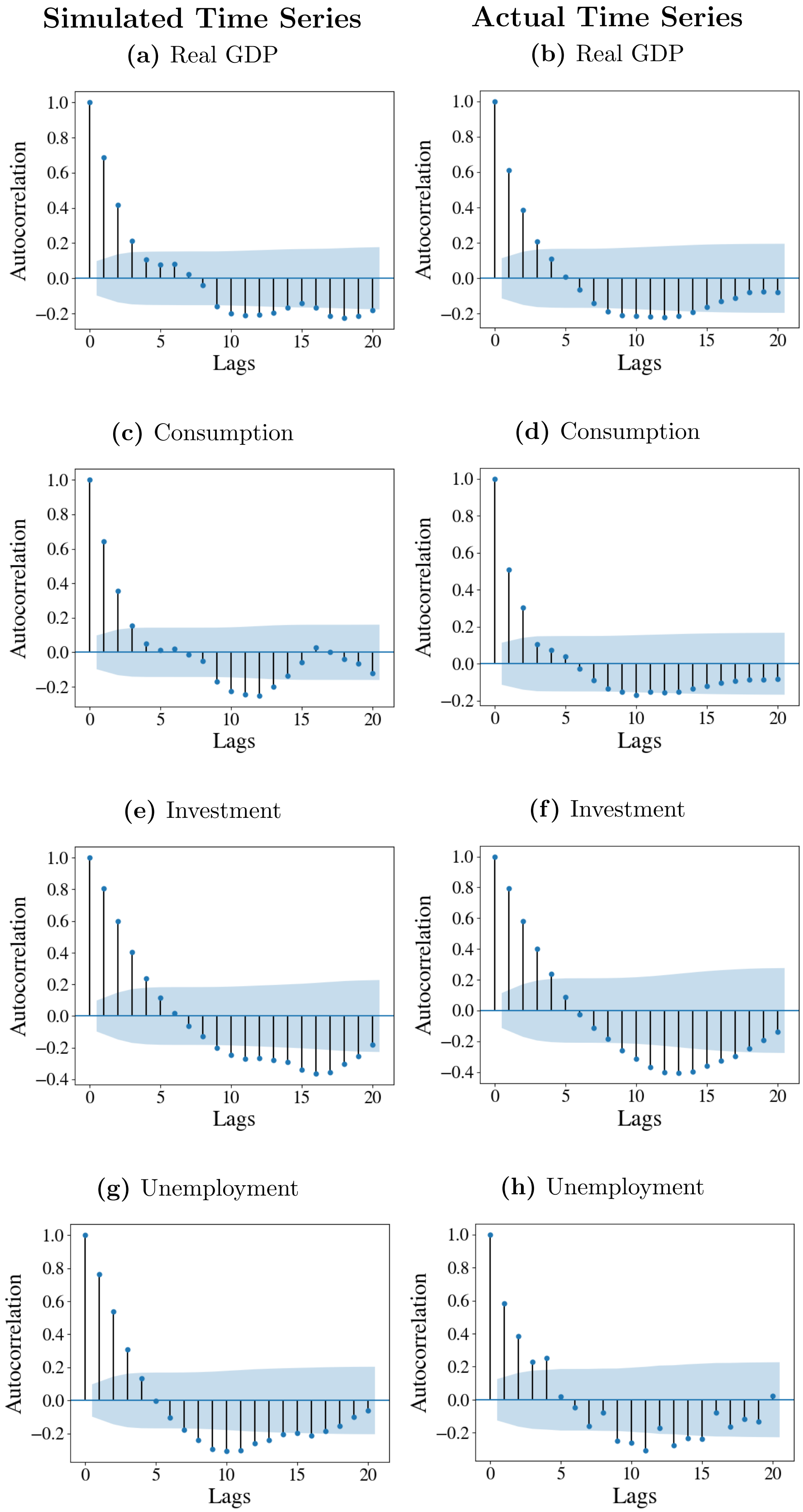


Figure 2: Cross Correlation of GDP with Key Macroeconomic Variables for Simulated and Actual Time Series

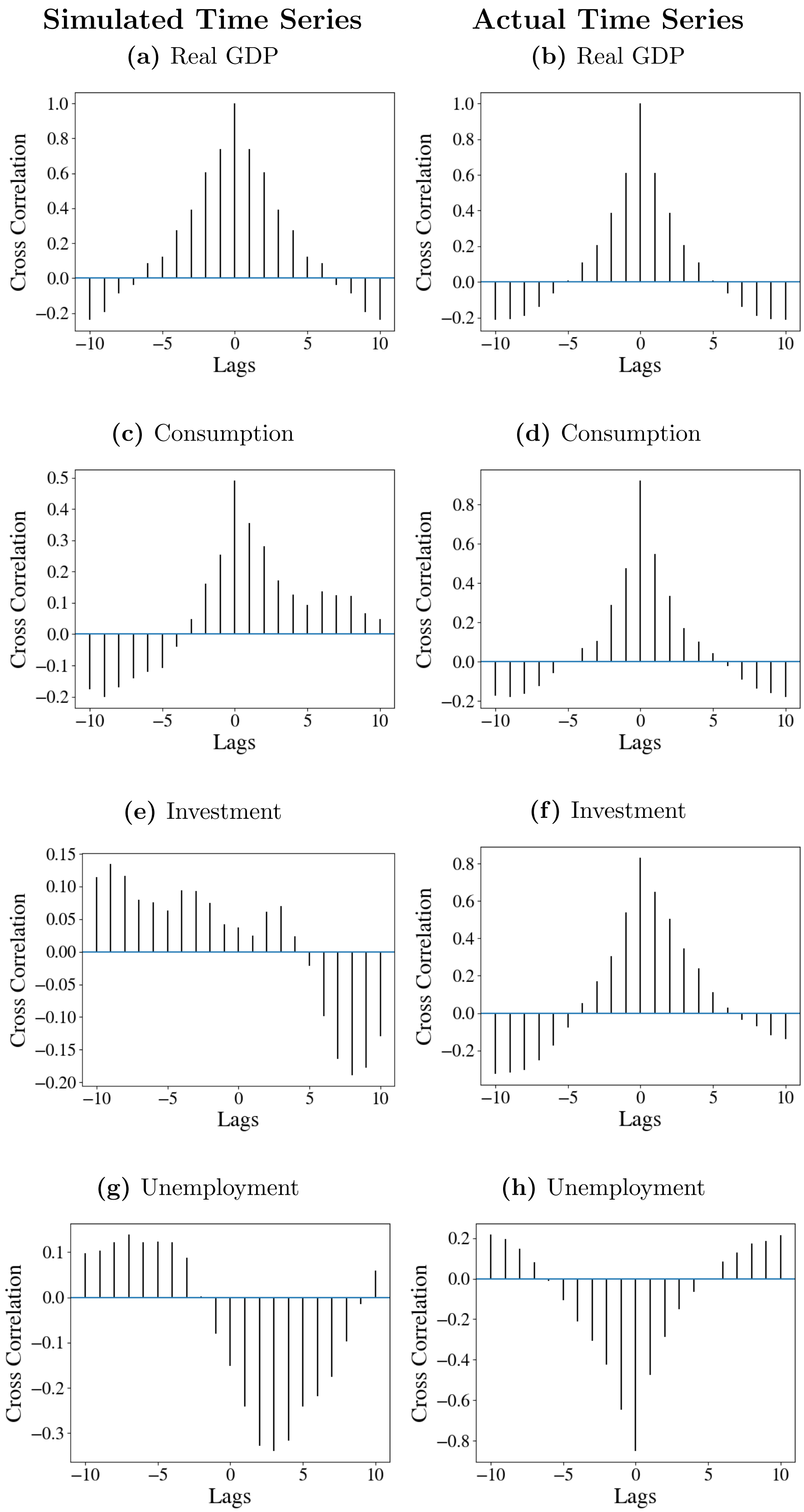


Table 1: Average values of simulations. Standard errors are in parenthesis and s.d. denotes standard deviation.

Scenario	GDP growth	GDP growth s.d.	Inflation	Inflation s.d.
Growth	0.007	0.067	0.046	0.011
	(0.0008)	(0.0015)	(0.0001)	(0.0002)
Zero-growth	0.002	0.052	0.052	0.011
	(0.0007)	(0.0012)	(0.0001)	(0.0003)

Herfindahl-Hirschman Index (HHI), which is a measure of relative market concentration, defined as[17] (Hirschman, 1945):

$$HHI_t = \sum_{\iota=1}^{M_F} = ms_{\iota,t}^2, \tag{38}$$

where $HHI_t \in (0,1)$ is the value of the index in time t, $ms_{\iota,t}$ is the market share of firm ι in time t, and M_F is the total number of firms in their given market. The closer HHI_t is to 1, the more concentrated the market is in time t. The Hymer-Pashigian Instability Index (HPI) was also used, given by (Hymer and Pashigian, 1962):

$$HPI_t = \sum_{\iota=1}^{M_F} = |ms_{\iota,t} - ms_{\iota,t-1}|. \tag{39}$$

where $HPI_t \in (0,1)$ measures the relative market share instability in time t. For HPI_t close to 1, this indicates that market shares are relatively more unstable. It is evident from panels 4a and 4b that the average capital good market (K-market) concentration is lower in the zero-growth scenario than in the growth scenario, particularly towards the end of the simulations. However, the difference in the consumption good market (C-market) is negligible. In panels 4c and 4d, it is clear that the instability of market shares is higher in the C-market of the zero-growth scenario than the C-market of the growth scenario. However, the instability of market shares in the K-market is higher in the growth scenario than the zero-growth scenario, although, by the end of the simulation they have similar values.

Moreover, Figure 5 displays the effects of each scenario on firms probability of going bankrupt and the average leverage ratio. From panels 5a and 5b it can be noted that in the zero-growth scenario firms are more likely to go bankrupt, furthermore, they are also likely to have a higher leverage ratio throughout the simulations, particularly towards the

[17] Orris C. Herfindahl also developed the statistic independently in his unpublished doctoral thesis "Concentration in the U.S. Steel Industry" (Columbia University, 1950).

end on the simulations. Suggesting that firms in the zero-growth scenario take on more debt compared to their liquidity than firms in the growth scenario. This could also explain the higher probability of firms going bankrupt in the zero-growth scenario.

Figure 6 presents analysis of the implications of zero-growth on households. From panels 6a and 6b it can be inferred that unemployment in the zero-growth scenario persists at a higher rate throughout the simulations when compared to the growth scenario, which starts off increasing but then, on average, begins to decline. The Gini Coefficient, which is a measure of household wealth inequality, for an ordered list of household wealth the gini coefficient in time t can be defined as (Dixon et al., 1987):

$$GI_t = \frac{1}{M_H}\left(M_H + 1 - 2\left(\frac{\sum_{h=1}^{M_H}(M_H + 1 - h)Y_{h,t}}{\sum_{h=1}^{M_H} Y_{h,t}}\right)\right). \tag{40}$$

It is apparent from panels 6c and 6d, that in the growth scenario household wealth inequality, as measured by the Gini Coefficient, is higher than in the zero-growth scenario. Therefore, this model goes against proposals from Piketty (2014, p. 84) in which he states that constant positive growth rates lead to a more equitable distribution of wealth. From panels 6e and 6f the wages share of output initially starts at a higher share in the growth scenario than the zero-growth scenario. Although, by the end of the simulation they approach a similar proportion. This result is different to that found in Barrett (2018), where, for the majority of simulation experiments, the wages share of output is higher in the zero-growth scenario than the growth scenario.

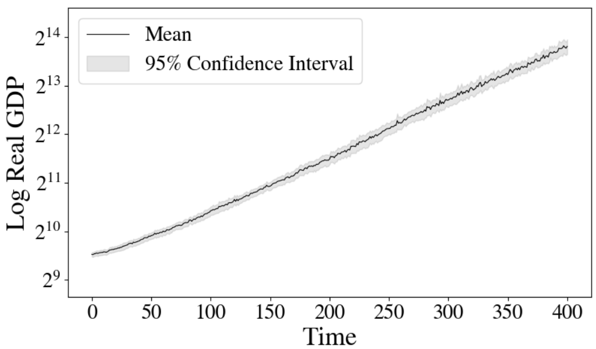
To summarise, the results comparing the simulated time series to the actual time series suggest that the model fairs relatively well in capturing similar cyclical behaviour. Although, the cross correlation of real GDP and investment is notably different. The results from the comparison of the two scenarios suggest that GDP growth was more stable in zero-growth scenario, however, inflationary pressure was higher. The markets seem to be similarly concentrated in both scenarios, due to the random processes employed in firm selection on the markets, although, the C-market was relative more unstable in the zero-growth scenario. Firms tended to have a higher probability of default in the zero-growth setting and also a higher persistent leverage ratio. Unemployment was also higher for a longer period of time in the zero-growth scenario, although wealth inequality was lower, with similar wages share of output by the end on the simulation, but both with decreasing trends.

Figure 3: Time series of macroeconomic variables with 95% confidence intervals

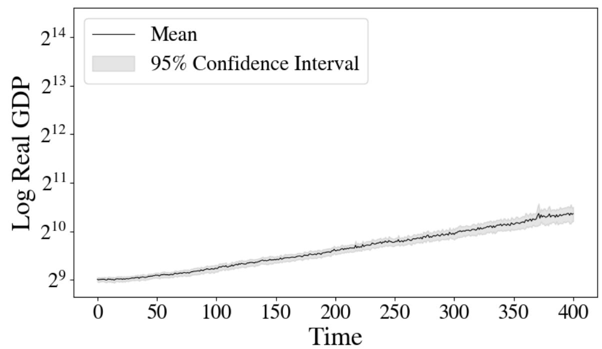
Growth Scenario

Zero-Growth Scenario

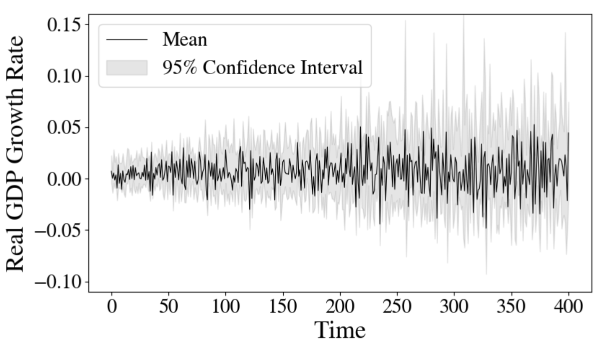
(a) Log Real GDP



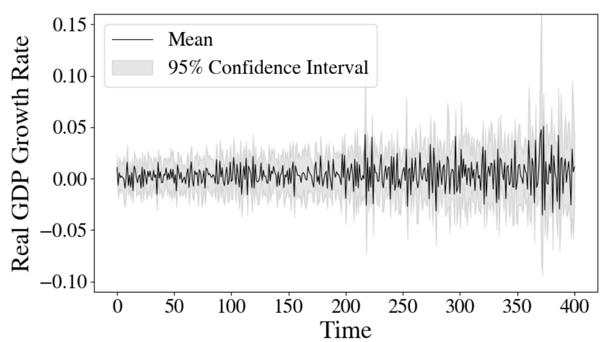
(b) Real GDP



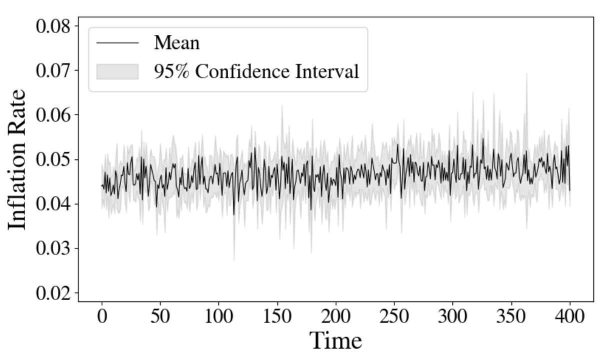
(c) Growth Rate



(d) Growth Rate



(e) Inflation



(f) Inflation

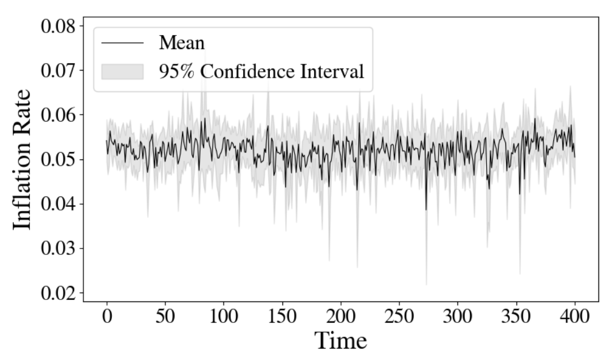
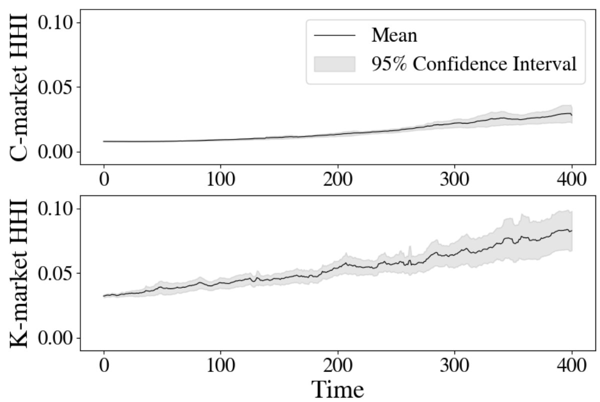


Figure 4: Time series of market stability variables with 95% confidence intervals

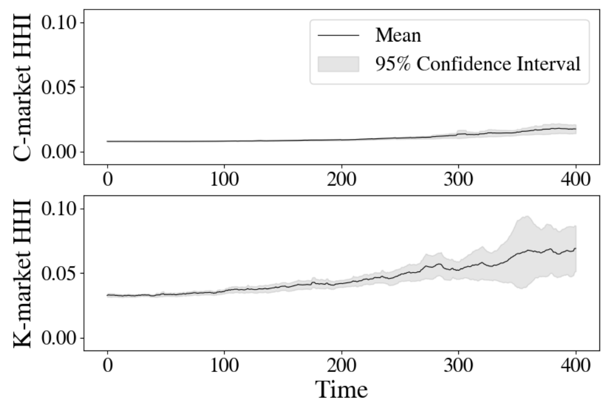
Growth Scenario

(a) Herfindahl-Hirschman Index (HHI)

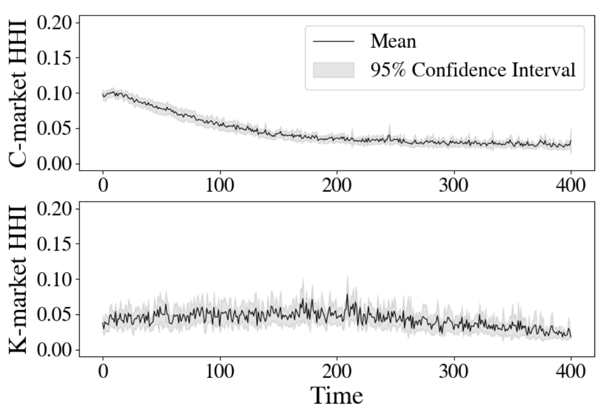


Zero-Growth Scenario

(b) Herfindahl-Hirschman Index (HHI)



(c) Hymer-Pashigian Instability Index (HPI)



(d) Hymer-Pashigian Instability Index (HPI)

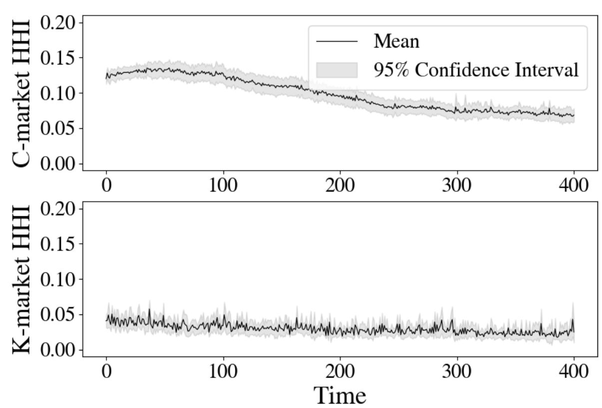
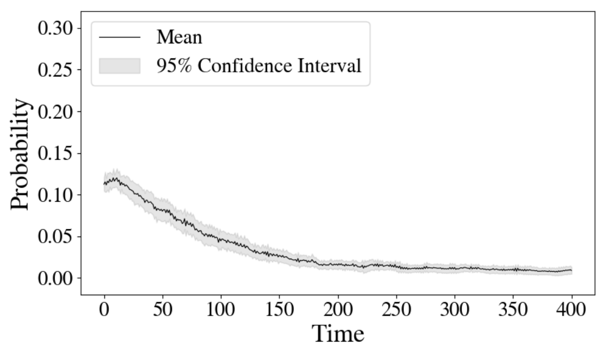
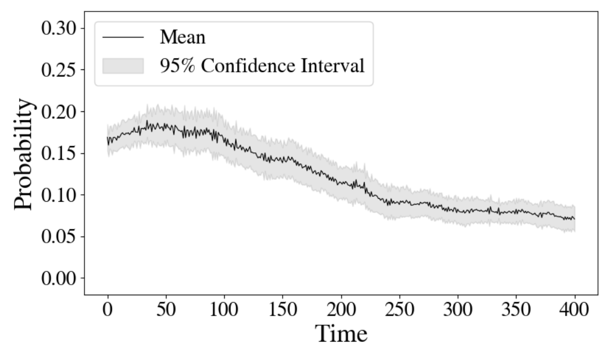


Figure 5: Time series of firm stability variables with 95% confidence intervals

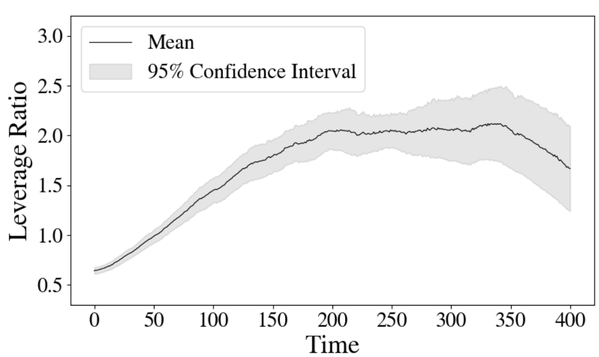
(a) Probability of Default



(b) Probability of Default



(c) Leverage



(d) Leverage

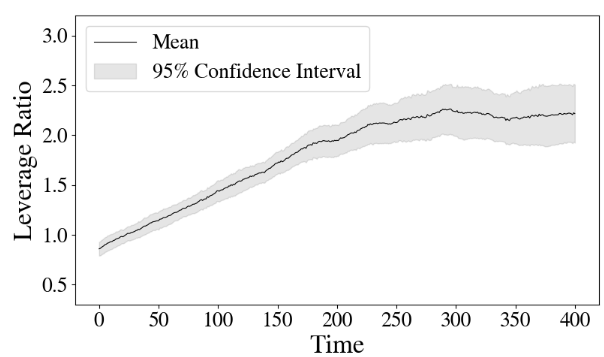
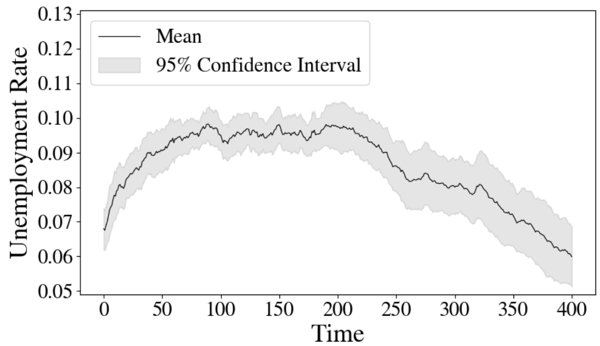


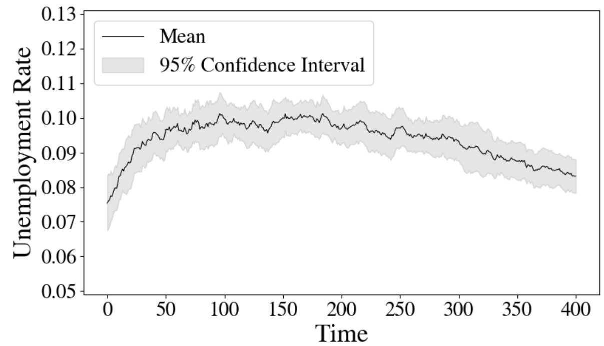
Figure 6: Time series of household and labour market variables with 95% confidence intervals

Growth Scenario	**Zero-Growth Scenario**

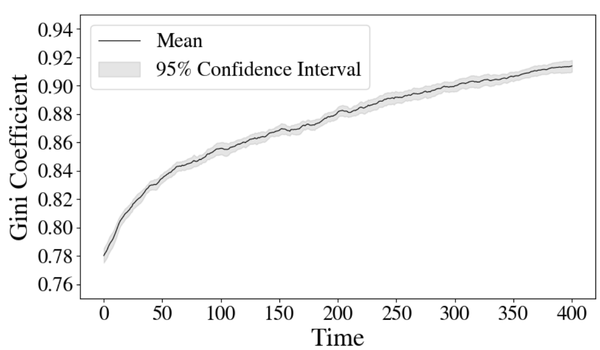
(a) Unemployment



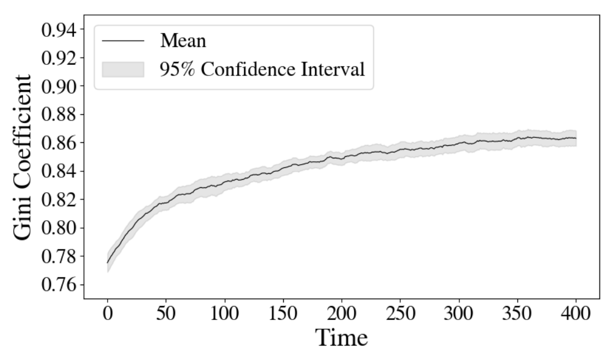
(b) Unemployment



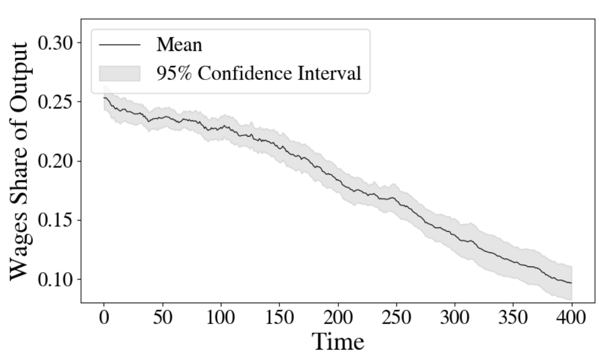
(c) Gini Coefficient



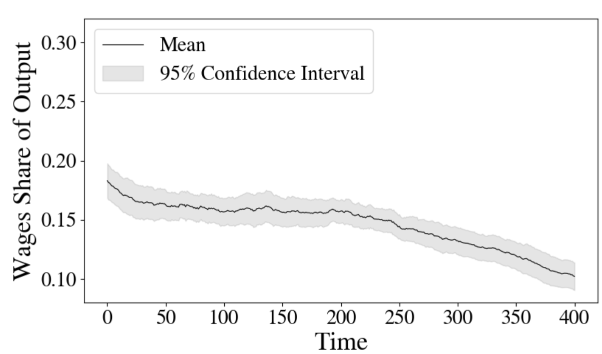
(d) Gini Coefficient



(e) Wages Share of Output



(f) Wages Share of Output



5 Limitations & Extensions

A main caveat of the model is the strict assumption of a closed economy, ABMs have previously been adopted to represent multiple countries interacting on a foreign market (Dosi et al., 2019). Furthermore, a Schumpeterian specification of capital firm's could also be adopted, as in the K&S and TRansit models. The inclusion of energy into the role of production could also be expanded, as in the TRansit model, providing a clear link to the impact on the environment between the two scenarios. A more developed financial sector with competition between many banks could also be employed, with an endogenously defined interest rate. The random selection process of firms on the C-market and K-market could also be expanded in which firms are chosen based on their market share. Furthermore, new methods recently developed in Delli Gatti and Grazzini (2020) have brought ABMs to the data. A further analysis of the stability of this model would also prove vital in determining the effects of zero-growth on the macroeconomy, as in Barrett (2018).

6 Concluding Remarks

This model is unique insofar as its comparison of a growth and zero-growth scenario done for a first time on a multi-agent macroeconomic ABM. This paper has shown that a stable zero productivity growth scenario, with interest bearing debt, was possible on the model. Moreover, it has been shown that the model, given a 2% labour productivity growth rate, captures the cyclical dynamics of autocorrelation relatively well, however, in reproducing the properties of cross correlation between the key macroeconomic variables the model falls short. Furthermore, the results found that real GDP growth rates were more stable in the zero-growth scenario and wealth inequality was lower. However, some of the consequences of zero-growth include increased instability for the C-market, a higher probability of bankruptcy and leverage ratio for firms, a higher level of unemployment throughout the simulation, and higher inflationary pressure. However, this paper demonstrates that the end of growth is not instability inducing on the economy, and could provide a new path for humanity to abate the strain of anthropogenic perturbations on the earths biophysical limits.

A Parameters & Initial Values

Table 2: Model Parameters & Initial Values

Symbol	Description	Value
T	The number of periods	1000
M_C	The number of C-firms	200
M_K	The number of K-firms	50
M_H	The number of households	1000
c_1	The marginal propensity to consume out of income	0.8
c_2	The marginal propensity to consume out of wealth	0.2
U_ψ	Maximum growth rate of prices	0.1
U_ξ	Maximum growth rate of firm wages	0.1
U_ζ	Maximum growth rate of households reservation wages	0.1
Z_C	Number of C-firms visited by households	3
Z_K	Number of K-firms visited by C-firms	3
Z_F	Number of job application sent to firms by households	5
g	Average growth rate of labour productivity	0.02 or 0
ν	Capital accelerator	3
β	Memory parameter of productivity growth	0.84
σ_α	Standard deviation of productivity growth	0.02
ρ	Planned production weight parameter	0.8
r	Interest rate on debt	0.02
ϕ	Repayment rate of debt	0.05
δ	Depreciation rate of capital	0.07
γ	Bank reserve ratio	0.1
θ	Bank attitude towards risk	0.01
$w_{h,0}$	Initial reservation wage of all households	1
$w_{\iota,0}$	Initial wage offered by all firms	1
$\bar{w}_0$	Initial minimum wage	1
$Y_{h,0}$	Initial income of all households	1
$K_{i,0}$	Initial capital of C-firms	3
$Y_{\iota,0}$	Initial output of all firms	1
$\hat{Y}_{\iota,0}$	Initial planned production of all firms	1
$a_{\iota,0}$	Initial labour productivity of all firms	1
$P_{\iota,0}$	Initial price of all firms	1

The models parameters were mostly chosen so as to avoid extremely unstable simulation paths for which the model would break down. Other parameters were chosen based on estimated values from real data, such as the average growth rate of labour productivity, standard deviation of productivity growth[18], capital acceleration and depreciation of capital[19] β was chosen so that there would be a correlation of 0.5 over the course of a year, every 4 periods. Furthermore, because a quarterly time step that was chosen, values that represent real world estimates were multiplied by 1/4 each period to represent the true growth over the course of a year. The initial values of the model were largely chosen based on normalisation of 1, all other variables in the model were initiated at 0. Hence, no attempt was made to calibrate the model to represent ex-post empirical data.

[18]Values were taken from the OECD, as in Barrett (2018), see data from; `https://data.oecd.org/lprdty/labour-productivity-and-utilisation.htm#indicator-chart`. For which 2% was a typical value for our g and σ_α parameters, during the economically stable period from 1981-2006

[19]Values for capital acceleration and depreciation were taken from Jackson and Victor (2015).

References

Assenza, T., Delli Gatti, D., and Grazzini, J. (2015) 'Emergent dynamics of a macroeconomic agent based model with capital and credit', *Journal of Economic Dynamics and Control*, 50, pp. 5–28.

Barrett, A. B. (2018) 'Stability of Zero-growth Economics Analysed with a Minskyan Model', *Ecological Economics*, 146, pp. 228–239.

Blanchard, O. (2018) 'On the future of macroeconomic models', *Oxford Review of Economic Policy*, 34(1-2), pp. 43–54.

Botte, F., Ciarli, T., Foxon, T., Jackson, A., Jackson, T., and Valente, M. (2021) 'Modelling Transition Risk Towards an agent-based, stock-flow consistent framework', *Rebuilding Macroeconomics Working Paper Series*, 40, pp. 1–65.

Delli Gatti, D., Di Guilmi, C., Gaffeo, E., Giulioni, G., Gallegati, M., and Palestrini, A. (2005) 'A new approach to business fluctuations: heterogeneous interacting agents, scaling laws and financial fragility', *Journal of Economic behavior & organization*, 56(4), pp. 489–512.

Delli Gatti, D., Gallegati, M., Giulioni, G., and Palestrini, A. (2003) 'Financial fragility, patterns of firms' entry and exit and aggregate dynamics', *Journal of economic behavior & organization*, 51(1), pp. 79–97.

Delli Gatti, D., Gallegati, M., Greenwald, B., Russo, A., and Stiglitz, J. E. (2010) 'The financial accelerator in an evolving credit network', *Journal of Economic Dynamics and Control*, 34(9), pp. 1627–1650.

Delli Gatti, D. and Grazzini, J. (2020) 'Rising to the challenge: Bayesian estimation and forecasting techniques for macroeconomic agent based models', *Journal of Economic Behavior & Organization*, 178, pp. 875–902.

Dixon, P. M., Weiner, J., Mitchell-Olds, T., and Woodley, R. (1987) 'Bootstrapping the Gini Coefficient of Inequality', *Ecology*, 68(5), pp. 1548–1551.

Dosi, G., Fagiolo, G., Napoletano, M., and Roventini, A. (2013) 'Income distribution, credit and fiscal policies in an agent-based keynesian model', *Journal of Economic Dynamics and Control*, 37(8), pp. 1598–1625.

Dosi, G., Fagiolo, G., and Roventini, A. (2006) 'An evolutionary model of endogenous business cycles', *Computational Economics*, 27(1), pp. 3–34.

Dosi, G., Fagiolo, G., and Roventini, A. (2009) ‘The microfoundations of business cycles: an evolutionary, multi-agent model’, in: ‘Schumpeterian Perspectives on Innovation, Competition and Growth’, pp. 161–180, Springer.

Dosi, G., Fagiolo, G., and Roventini, A. (2010) ‘Schumpeter meeting Keynes: A policy-friendly model of endogenous growth and business cycles’, *Journal of Economic Dynamics and Control*, 34(9), pp. 1748–1767.

Dosi, G., Roventini, A., and Russo, E. (2019) ‘Endogenous growth and global divergence in a multi-country agent-based model’, *Journal of Economic Dynamics and Control*, 101, pp. 101–129.

Gaffeo, E., Delli Gatti, D., Desiderio, S., and Gallegati, M. (2008) ‘Adaptive Microfoundations for Emergent Macroeconomics’, *Eastern Economic Journal*, 34(4), pp. 441–463.

Hirschman, A. O. (1945) *National Power and the Structure of Foreign Trade*, Los Angeles: University of California Press.

Hymer, S. and Pashigian, P. (1962) ‘Turnover of firms as a measure of market behavior’, *The Review of Economics and Statistics*, 44(1), pp. 82–87.

Jackson, T. and Victor, P. A. (2015) ‘Does credit create a ‘growth imperative’? A quasi-stationary economy with interest-bearing debt’, *Ecological Economics*, 120, pp. 32–48.

Keen, S. (1995) ‘Finance and economic breakdown: Modeling minsky’s “financial instability hypothesis”’, *Journal of Post Keynesian Economics*, 17(4), pp. 607–635.

Keynes, J. M. (2010) ‘Economic possibilities for our grandchildren’, in: ‘Essays in persuasion’, pp. 321–332, Springer.

Lucas Jr, R. E. (1976) ‘Econometric policy evaluation: A critique’, in: ‘Carnegie-Rochester conference series on public policy’, vol. 1, pp. 19–46.

Malmaeus, J. M. and Alfredsson, E. C. (2017) ‘Potential Consequences on the Economy of Low or No Growth - Short and Long Term Perspectives’, *Ecological Economics*, 134, pp. 57–64.

Mankiw, N. G. (2006) ‘The macroeconomist as scientist and engineer’, *Journal of Economic Perspectives*, 20(4), pp. 29–46.

Meadows, D. L., Meadows, D. H., Randers, J., and Behrens III, W. W. (1972) *The Limits to Growth*, New York: Universe Books.

Mill, J. S. (1884) *Principles of political economy*, New York: D. Appleton.

Minsky, H. P. (1986) *Stabilizing an Unstable Economy*, vol. 1, New Haven: Yale University Press.

Piketty, T. (2014) *Capital in the twenty-first century*, Cambridge, Massachusetts: Harvard University Press.

Rostow, W. W. (1960) *The Stages of Economic Growth, a Non-Communist Manifesto*, London, New York: Cambridge University Press.

Russo, A., Catalano, M., Gaffeo, E., Gallegati, M., and Napoletano, M. (2007) 'Industrial dynamics, fiscal policy and r&d: Evidence from a computational experiment', *Journal of Economic Behavior & Organization*, 64(3-4), pp. 426–447.

Schumacher, E. F. (1973) *Small is beautiful: A study of economics as if people mattered*, London: Blond & Briggs.

Schumpeter, J. A. (1942) *Capitalism, Socialism and Democracy*, New York: Harper & Brothers.

Solow, R. (2010) 'Building a science of economics for the real world', *House Committee on Science and Technology Subcommittee on Investigations and Oversight*, 20.

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., and Sorlin, S. (2015) 'Planetary boundaries: Guiding human development on a changing planet', *Science*, 347(6223), 1259855–1259855.